

# Device Drivers



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## Overview

- Device drivers implement a uniform interface to varied hardware devices
  - ◆ This allows the rest of the kernel to be hardware-independent
- Device drivers convert high-level function calls, like `read()`, into specific hardware commands
  - ◆ These commands are typically reads/writes to specific addresses in the physical address space that are assigned to each device
  - ◆ Long-latency commands signal completion via interrupts
- Note that device drivers may be layered
  - ◆ eg, a command may first be handled by a device driver that manages bus transactions, then a device driver that controls the specific device



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## Memory-Mapped I/O

- Regions of the physical address space are assigned to each device on the bus
  - ◆ These addresses are usually only accessible by the kernel
  - ◆ Multiple devices may share a single controller

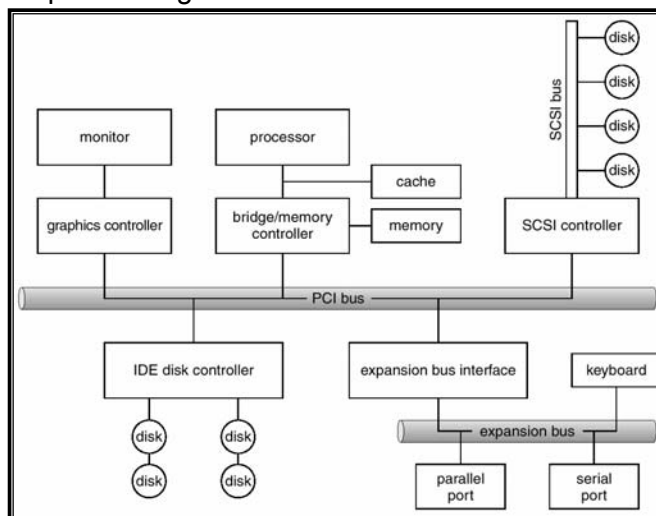


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## Typical Bus Organization

- Example bus organization:



Source: Silberschatz, Galvin and Gagne, ©2002.  
<http://cs-www.cs.yale.edu/homes/awlos-book/ios/index.html>



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## Memory-Mapped I/O, cont.

I/O address range (hexadecimal)	device
000-00F	DMA controller
020-021	interrupt controller
040-043	timer
200-20F	game controller
2F8-2FF	serial port (secondary)
320-32F	hard-disk controller
378-37F	parallel port
3D0-3DF	graphics controller
3F0-3F7	diskette-drive controller
3F8-3FF	serial port (primary)

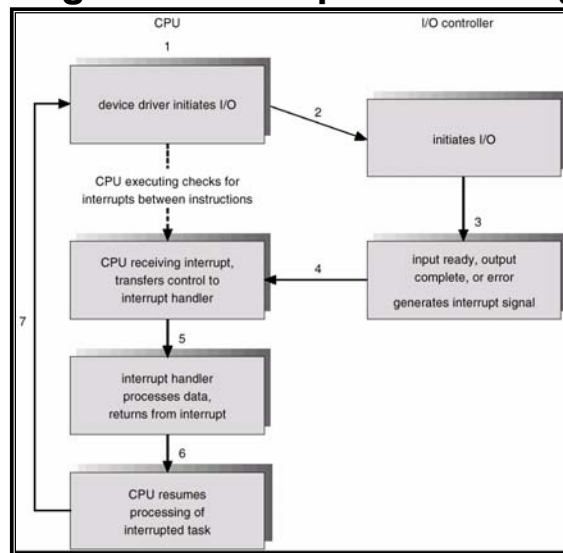
Source: Silberschatz, Galvin and Gagne, ©2002  
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## Stages of Interrupt Processing



Source: Silberschatz, Galvin and Gagne, ©2002  
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## Sample Interrupts

vector number	description
0	divide error
1	debug exception
2	null interrupt
3	breakpoint
4	INT0-detected overflow
5	bound range exception
6	invalid opcode
7	device not available
8	double fault
9	coprocessor segment overrun (reserved)
10	invalid task state segment
11	segment not present
12	stack fault
13	general protection
14	page fault
15	(Intel reserved, do not use)
16	floating-point error
17	alignment check
18	machine check
19-31	(Intel reserved, do not use)
32-255	maskable interrupts

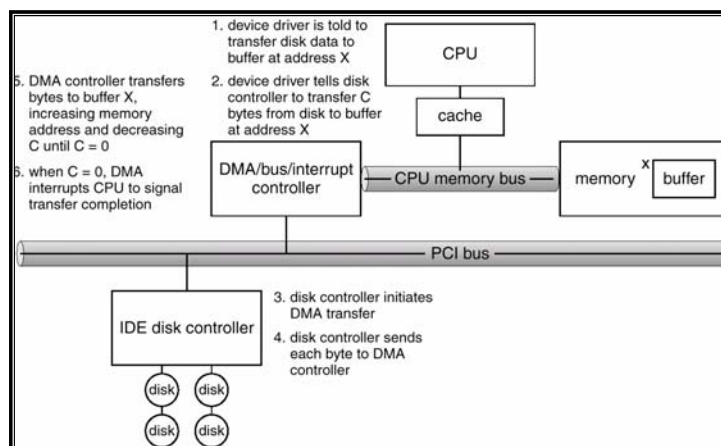
Source: Silberschatz, Galvin and Gagne, ©2002  
<http://cs-www.cs.yale.edu/homes/awlos-book/isc/index.html>



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## Stages of DMA



Source: Silberschatz, Galvin and Gagne, ©2002  
<http://cs-www.cs.yale.edu/homes/awlos-book/isc/index.html>

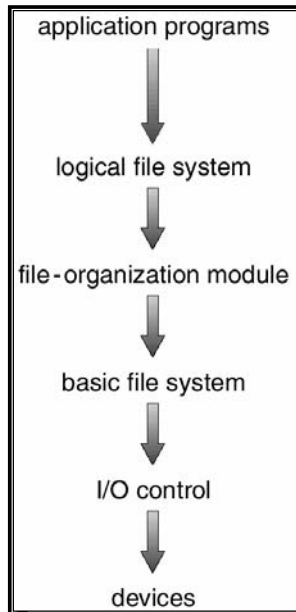


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## Device Infrastructure

- Hierarchy of abstraction
  - ◆ Device-dependence is confined to I/O control and device driver layers



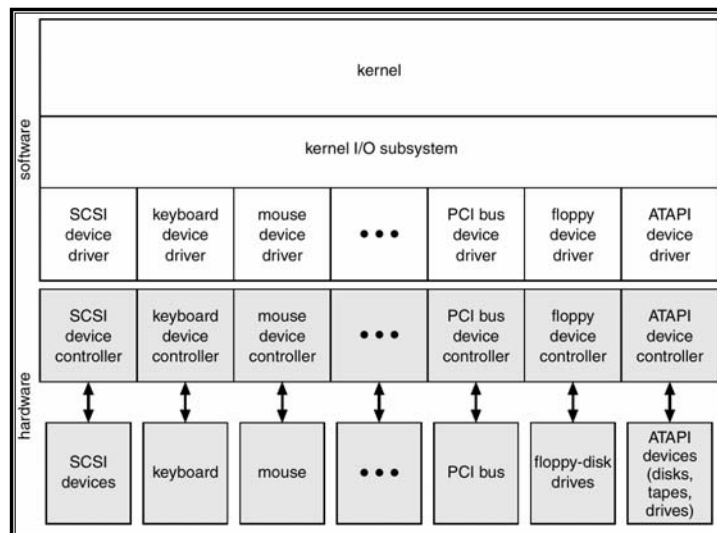
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## Kernel I/O Structure



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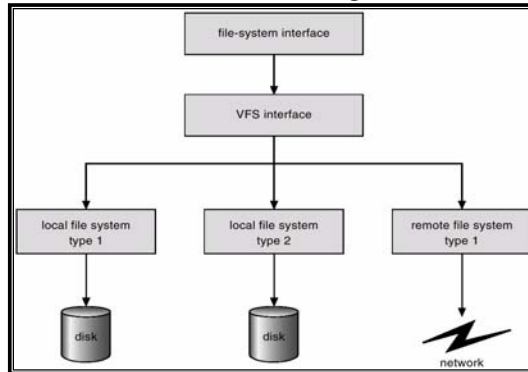


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## More abstraction: Virtual File System

- Even the file system has several layers



- *Virtual File System (VFS)* layer – distinguishes local files from remote ones, and local files are further distinguished according to their file-system types.

- ◆ The VFS activates file-system-specific operations to handle local requests according to their file-system types.
- ◆ Calls the NFS protocol procedures for remote requests.

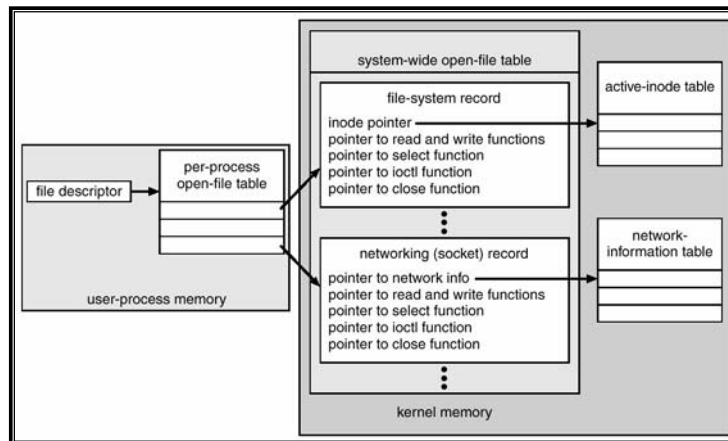


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<http://cs-www.cs.yale.edu/homes/awlos-book/osi/index.html>

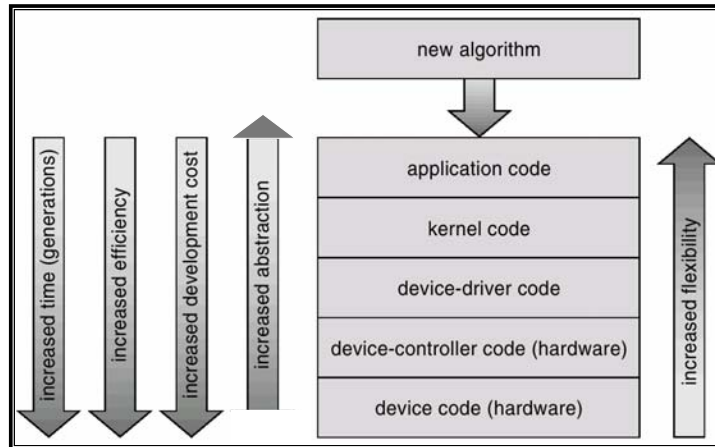
## Unix File-Access Control Structure



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Source: Silberschatz, Galvin and Gagne ©2002  
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Modified from: Silberschatz, Galvin and Gagne ©2002.  
<http://cs-www.cs.yale.edu/home/silberschatz/book/sec/index.html>



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## Device-Independent System Call/Interrupt Handling

```
Funci(...) -> dev_func_i(devID, ...) {
    // Processing common to all devices
    ....
    switch(devID) {
        case dev0: dev0_func_i(...);
                    break;
        case dev1: dev1_func_i(...);
                    break;
        ...
    }
    // Processing common to all devices
}
```

Adapted from G. Nutt, "Operating Systems", 3<sup>rd</sup> ed., ©2004



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## Example: Linux

```
struct file_operations{
    loff_t (*llseek) (struct file *, loff_t, int);
    ssize_t (*read) (struct file *, char *, size_t, loff_t *)
    ...
}

foo_init() {
    ...
    struct file_operations foo_fops = {
        NULL;          /* llseek – not used */
        foo_read;       /* read function */
        ...
    }
}
```

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## Example Device Driver Internals

- Interrupt handler for keyboard
  - ◆ (see <http://www.ibiblio.org/navigator-bin/navigator.cgi?drivers/char/keyboard.c>)
    - On screen

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## Review: Stages in Processing an I/O Call

- Application makes call to C library function, eg `fscanf()`
- C library translates this into a system call, eg `read()`
- Execute syscall instruction
- Trap vector processes file name, determines which device is being accessed
  - ◆ This may entail additional disk accesses
- VFS consulted
- Appropriate local file system is consulted (or NFS access)
- File name -> inode -> block number
- Read(block num) call to device driver
  - ◆ Device driver should check input validity, avoid buffer overflow
  - ◆ Device driver checks device status; if busy, request is queued
- Read command issued over bus
  - ◆ This may actually entail a series of back-and-forth bus transactions
- Hardware controller performs read
- Interrupt generated when read completes
- Interrupt handler calls appropriate handler func in device driver



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## Interrupt Processing

- Interrupt hardware saves some registers, indexes kernel's interrupt vector
- Kernel can ignore interrupt or proceed
- If proceeding, kernel typically temporarily suspends interrupts
- Kernel saves registers and sets up context for the interrupt service procedure
  - ◆ If a user process was running, this requires a context switch, TLB/MMU setup, and creation of a stack
- Run the "top half" of the interrupt service procedure
- Re-enable interrupts
- Finish interrupt servicing
- This may make a process runnable
- Choose which process to run
- Call kernel scheduler



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## Re-entrant Code

- Note that an interrupt may be received at any time unless interrupts are disabled
  - ◆ While kernel is running
  - ◆ While device driver is handling a system call
  - ◆ While device driver is handling an interrupt
- Disabling interrupts briefly allows kernel/drivers to do minimal work necessary to maintain a coherent state, then interrupts can be re-enabled

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## More Complexity: Hot-Swappable Devices

- Some devices can be installed or removed while computer runs, eg USB devices
- Either action generates an interrupt
- On an install, kernel must find, (install if necessary), and initialize the device driver
- On a removal, kernel must shut down the device driver and gracefully deal with pending requests
  - ◆ eg, Waiting processes shouldn't hang

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